

Example 1a

June 17, 2020

1 Example 1a: Harmonic trap - Training of DeepCalib

Example code to train DeepCalib to determine the stiffness of a Brownian particle system in a harmonic trap.

DeepCalib 1.0 Enhanced force-field calibration via machine learning version 1.0 - 27 April 2020
Aykut Argun, Tobias Thalheim, Stefano Bo, Frank Cichos & Giovanni Volpe [Soft Matter Lab](#)

1.1 1. INIZIALIZATION

```
In [1]: import DeepCalib
```

1.2 2. DEFINE TRAJECTORY SIMULATION

Here the function that simulates the motion of the Brownian particle in the force field under consideration is defined. Specifically, in this case, we consider a Brownian particle in a harmonic force field, and the motion of the particle depends on the trap stiffness k .

This file is used to reproduce results that are shown in Fig.1 and generate the pretrained network "DeepCalib_Example 1a.h5" that is going to be needed to execute Example 1b.

Comments: 1. The function that simulates the trajectories must be called `simulate_trajectory`.
2. Lambda functions `scale_inputs`, `rescale_inputs`, `scale_targets`, and `rescale_targets` must also be defined. For the best performance of the learning, the rescaling of both the inputs and targets should lead to values of order 1.

```
In [2]: ### Physical parameters
        from math import pi
        R = 1e-7                                # Radius of the Brownian particle [m]
        eta = 0.001                             # Viscosity of the medium [kg m^-1 s^-1]
        T = 300                                 # Temperature [K]
        k0 = 10                                 # Reference stiffness [fN \mu m^-1]
        gamma0 = 6 * pi * eta * R               # Reference friction coefficient [kg s^-1]

        ### Simulation parameters
        N = 1000                                # Number of samples of the trajectory
        Dt = 1e-2                               # Timestep
        oversampling = 5                        # Simulation oversampling
        offset = 1000                           # Number of equilibration timesteps
```

```

### Define functions to scale and rescale inputs
scale_inputs = lambda x: x * 1e+6 # Scales input trajectory to order
rescale_inputs = lambda scaled_x: scaled_x * 1e-6 # Rescales input trajectory to phys

### Define function to scale and rescale targets
from numpy import log
from numpy import exp
scale_targets = lambda k: log(k / k0) # Scales targets to
rescale_targets = lambda scaled_k: exp(scaled_k) * k0 # Inverse of targets

### Define the simulate_trajectory function

def simulate_trajectory(batch_size=32,
                        T=T,
                        k0=k0,
                        gamma0=gamma0,
                        N=N,
                        Dt=Dt,
                        oversampling=oversampling,
                        offset=offset,
                        scale_inputs=scale_inputs,
                        scale_targets=scale_targets):

    """Simulates a Brownian particle in a harmonic trap

Inputs:

T: temperature of the environment
k0: center of the stiffness range
gamma0: friction coefficient
N: number of trajectory data points
Dt: measurement period
oversampling: oversampling from the simulation time step (to calculate dt)
offset: steps of the simulation before starting to save the trajectory
scale_inputs: inputs scale function for the network, to normalize it comparable to
scale_targets: targets scale function for the network, to normalize it comparable to

Outputs:

inputs: the inputs for the network, these are trajectories that have the following f

        inputs.names: names of the input trajectory variables ('x', 'y' etc
        inputs.values: values of the inputs in SI units
        inputs.scalings: short description of the scaling function for the inp
        inputs.scaled_values: scaled values of the inputs to be passed to the netwo

targets: the expected ground truth measurements for the trajectory that have follow

```

```

        targets.names:          names of the targets to be measures ('k' etc)
        targets.values:         values of the ground truth targets in SI units
        targets.scalings:       short description of the scaling function for the targets
        targets.scaled_values:   scaled values of the ground truth targets to be passed
    """

import numpy as np
from scipy.constants import Boltzmann as kB
from math import pi
from math import sqrt
from numpy.random import randn as gauss
from numpy.random import rand as uniform

### Randomize trajectory parameters

k = k0 * (10*(uniform(batch_size) * 3 - 1.5))    # Generates random stiffness values
gamma = gamma0 * (uniform(batch_size) * .1 + .95) # Marginal randomization of friction

### Simulate

dt = Dt / oversampling                        # time step of the simulation
x = np.zeros((batch_size, N))                # initialization of the x array
D = kB * T / gamma                           # diffusion coefficient
C1 = -k * 1e-9 / gamma * dt                   # drift coefficient of the Langevin equation
C3 = np.sqrt(2 * D * dt)                     # random walk coefficient of the Langevin equation
X = x[:, 0]
n = 0

for t in range(offset):                      # Offset (for some prerun before running)
    X = X + C1 * X + C3 * gauss(batch_size)

for t in range(N * oversampling):            # Simulation
    X = X + C1 * X + C3 * gauss(batch_size)
    if t % oversampling == 0:                 # We save every oversampling-th values
        x[:, n] = X
        n += 1

# Normalize trajectory and targets

inputs = DeepCalib.trajectory(
    names=['x'],
    values=x,
    scalings=['x [\u03BCm]'],
    scaled_values=scale_inputs(x))

targets = DeepCalib.targets(
    names=['k [fN/\u03BCm]'],
    values=k,

```

```

scalings=['log(k / k0)'],
scaled_values=scale_targets(k))

return inputs, targets

```

1.3 3. CHECK TRAJECTORY SIMULATION

Checks the results of the function to simulate the trajectories by plotting some examples in rescaled units.

Have a look at the trajectories and check if they match your system, and keep an eye on different trajectories and make sure your scaled units vary in the order of 1, i.e, neither too small (0.01 or smaller) nor too large (100 or larger)

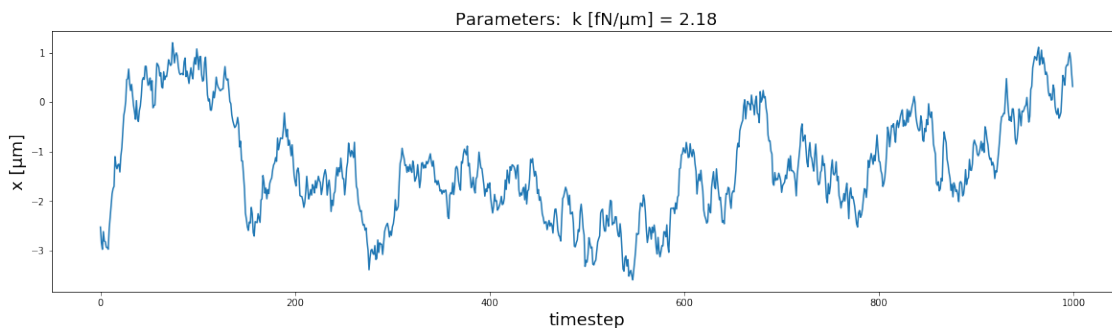
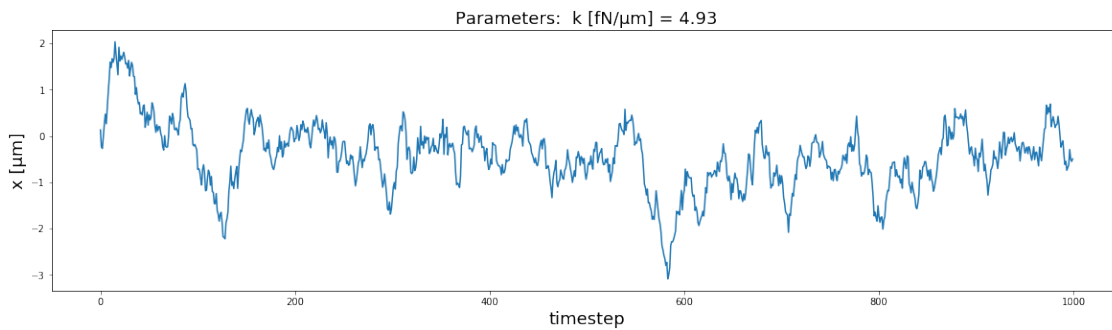
The parameter `number_of_images_to_show` determines the number of trajectories that are plotted.

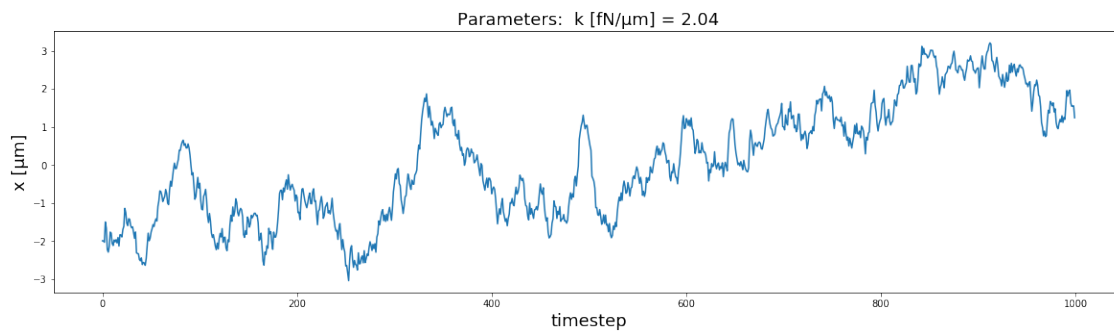
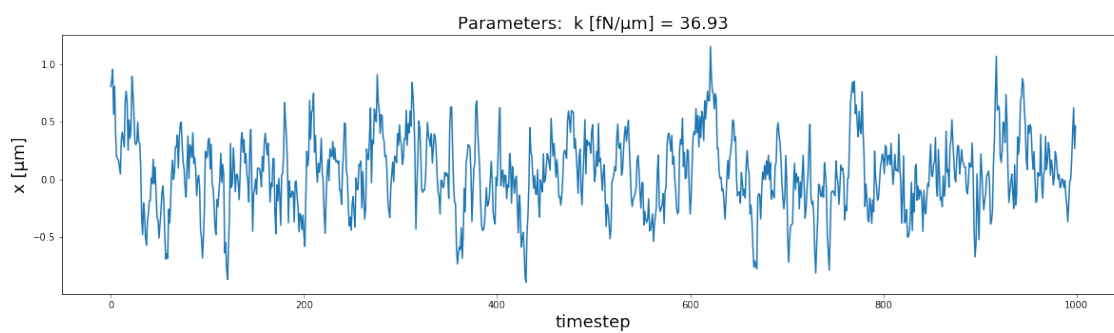
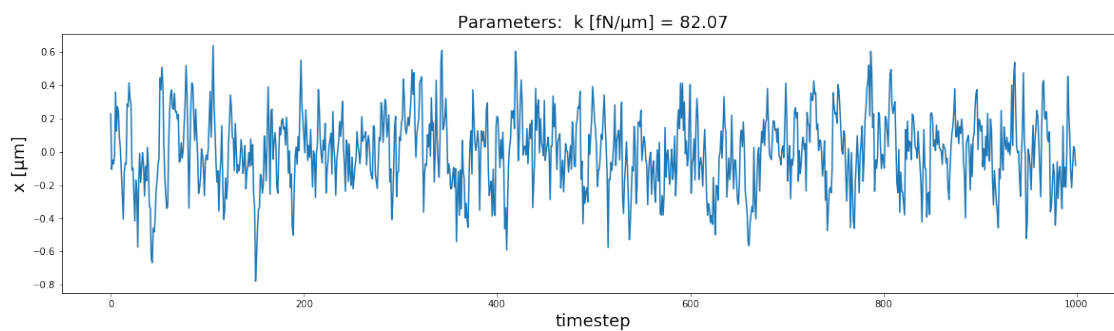
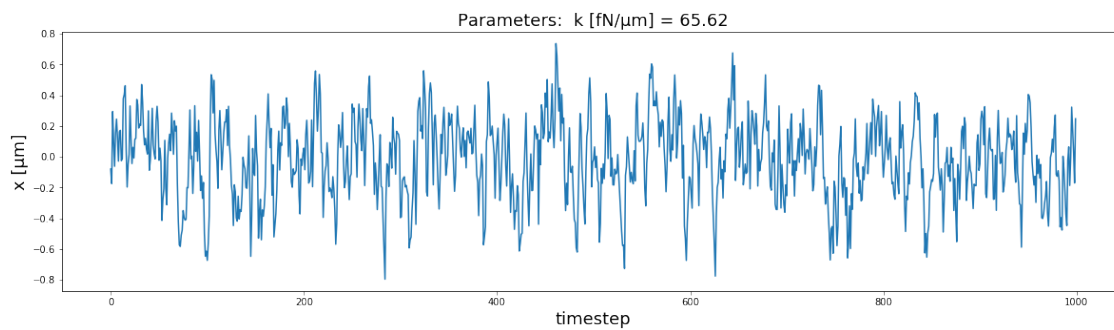
In [3]: *### Show some examples of simulated trajectories*

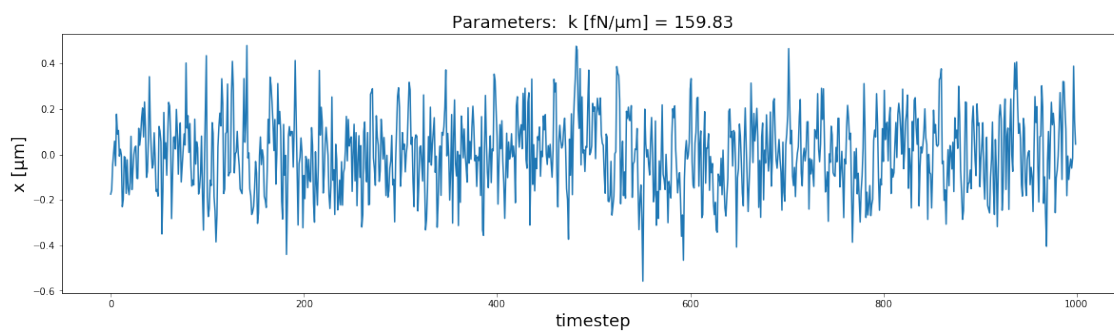
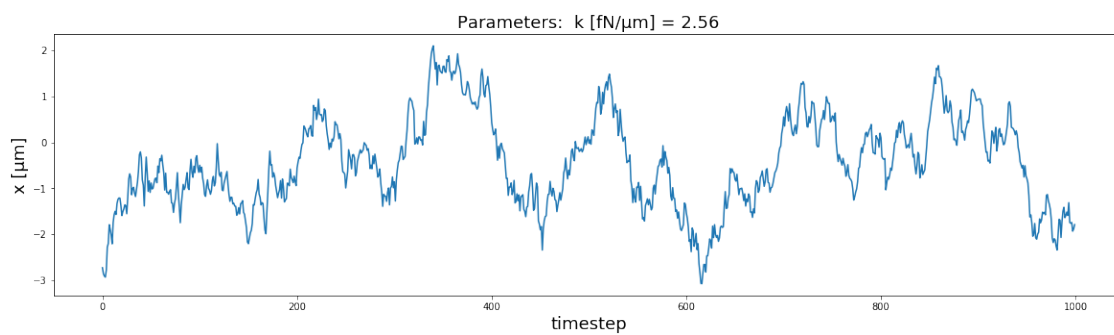
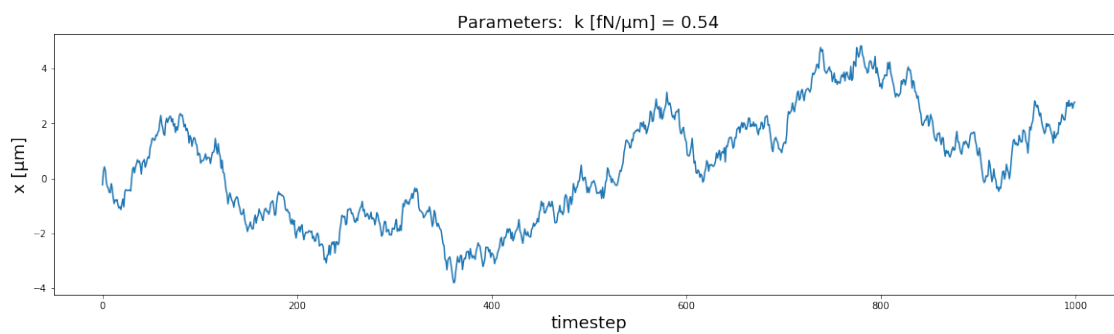
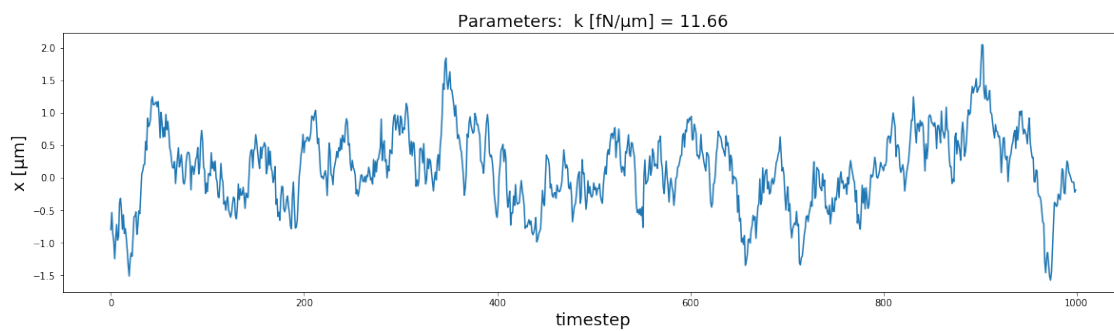
```

number_of_trajectories_to_show = 10
%matplotlib inline
DeepCalib.plot_sample_trajectories(simulate_trajectory, number_of_trajectories_to_show)

```







1.4 4. CREATE AND COMPILE DEEP LEARNING NETWORK

The parameters of the deep learning network are defined and the network created. The summary of the network is printed where the output shape and number of parameters for each layer can be visualized.

Comments: 1. The parameter `input_shape` determines the shape of the input sequence, given by the number of time-steps times the number of samples in each input sequence. Make sure your input shape dimensions match the length of the input trajectory, in this example $2 \times 500 = 1000$. 2. The parameter `conv_layers_dimensions` determines the number and size of LSTM layers. 3. The parameter `number_of_outputs` determines the number of outputs, i.e. the number of force field parameters to be estimated.

```
In [6]: ### Define parameters of the deep learning network
        input_shape = (20, 50)
        lstm_layers_dimensions = (1000, 250, 50)
        number_of_outputs = 1

        ### Create deep learning network
        network = DeepCalib.create_deep_learning_network(input_shape, lstm_layers_dimensions, nu

        ### Print deep learning network summary
        network.summary()
```

Layer (type)	Output Shape	Param #
lstm_1 (LSTM)	(None, 20, 1000)	4204000
lstm_2 (LSTM)	(None, 20, 250)	1251000
lstm_3 (LSTM)	(None, 50)	60200
output (Dense)	(None, 1)	51

=====
Total params: 5,515,251
Trainable params: 5,515,251
Non-trainable params: 0
=====

1.5 5. TRAIN DEEP LEARNING NETWORK

The parameters for the training of the deep learning network are defined and the network is trained. The sample size, iteration number, MSE, MAE and the time of each iteration is printed.

Comments: 1. The parameter `sample_sizes` determines the sizes of the batches of trajectories used in the training. 2. The parameter `iteration_numbers` determines the numbers of batches used

in the training. 3. The parameter verbose determines the frequency of the update messages. It can be either a boolean value (True/False) or a number between 0 and 1.

```
In [7]: ### Define parameters of the training
```

```
sample_sizes = (32, 128, 512, 2048)
```

```
iteration_numbers = (1001, 1001, 1001, 2001)
```

```
verbose = .1
```

```
### Training
```

```
training_history = DeepCalib.train_deep_learning_network(network, simulate_trajectory, s
```

Sample size	32	iteration number	1	MSE	3.4480	MAE	1.5706	Time	4950.63829
Sample size	32	iteration number	11	MSE	0.7324	MAE	0.7497	Time	107.949018
Sample size	32	iteration number	21	MSE	0.4827	MAE	0.5501	Time	106.871605
Sample size	32	iteration number	31	MSE	0.4117	MAE	0.5009	Time	108.043909
Sample size	32	iteration number	41	MSE	0.2653	MAE	0.4318	Time	116.273880
Sample size	32	iteration number	51	MSE	0.2784	MAE	0.4105	Time	106.824636
Sample size	32	iteration number	61	MSE	0.2289	MAE	0.4020	Time	108.572006
Sample size	32	iteration number	71	MSE	0.2677	MAE	0.3815	Time	113.693476
Sample size	32	iteration number	81	MSE	0.2203	MAE	0.3974	Time	110.285759
Sample size	32	iteration number	91	MSE	0.1720	MAE	0.3497	Time	107.877016
Sample size	32	iteration number	101	MSE	0.2022	MAE	0.3429	Time	109.894753
Sample size	32	iteration number	111	MSE	0.0810	MAE	0.2347	Time	110.737801
Sample size	32	iteration number	121	MSE	0.3150	MAE	0.3838	Time	109.421492
Sample size	32	iteration number	131	MSE	0.2613	MAE	0.4121	Time	109.548330
Sample size	32	iteration number	141	MSE	0.3225	MAE	0.4410	Time	108.907938
Sample size	32	iteration number	151	MSE	0.2543	MAE	0.4201	Time	106.597185
Sample size	32	iteration number	161	MSE	0.1407	MAE	0.2848	Time	108.760357
Sample size	32	iteration number	171	MSE	0.1853	MAE	0.3121	Time	110.108376
Sample size	32	iteration number	181	MSE	0.1198	MAE	0.2759	Time	107.394218
Sample size	32	iteration number	191	MSE	0.0936	MAE	0.2560	Time	105.220556
Sample size	32	iteration number	201	MSE	0.1455	MAE	0.3112	Time	108.553410
Sample size	32	iteration number	211	MSE	0.1810	MAE	0.3421	Time	116.151333
Sample size	32	iteration number	221	MSE	0.1208	MAE	0.2442	Time	106.971264
Sample size	32	iteration number	231	MSE	0.1077	MAE	0.2539	Time	105.203152
Sample size	32	iteration number	241	MSE	0.2725	MAE	0.3981	Time	122.049809
Sample size	32	iteration number	251	MSE	0.0668	MAE	0.2123	Time	107.476711
Sample size	32	iteration number	261	MSE	0.0984	MAE	0.2435	Time	109.340668
Sample size	32	iteration number	271	MSE	0.1954	MAE	0.3267	Time	118.575335
Sample size	32	iteration number	281	MSE	0.0741	MAE	0.2260	Time	106.934071
Sample size	32	iteration number	291	MSE	0.1426	MAE	0.2905	Time	107.014418
Sample size	32	iteration number	301	MSE	0.2260	MAE	0.3590	Time	115.519524
Sample size	32	iteration number	311	MSE	0.1538	MAE	0.3042	Time	106.220722
Sample size	32	iteration number	321	MSE	0.1707	MAE	0.3262	Time	108.341217
Sample size	32	iteration number	331	MSE	0.1702	MAE	0.2855	Time	111.816883
Sample size	32	iteration number	341	MSE	0.2863	MAE	0.3770	Time	116.181612
Sample size	32	iteration number	351	MSE	0.0703	MAE	0.1915	Time	107.507944
Sample size	32	iteration number	361	MSE	0.0644	MAE	0.1929	Time	111.064434

Sample size	32	iteration number	371	MSE	0.1068	MAE	0.2621	Time	105.543375
Sample size	32	iteration number	381	MSE	0.3928	MAE	0.4599	Time	110.954762
Sample size	32	iteration number	391	MSE	0.0798	MAE	0.2302	Time	113.655806
Sample size	32	iteration number	401	MSE	0.0702	MAE	0.2217	Time	112.026453
Sample size	32	iteration number	411	MSE	0.2004	MAE	0.3760	Time	107.377529
Sample size	32	iteration number	421	MSE	0.1245	MAE	0.2531	Time	107.088566
Sample size	32	iteration number	431	MSE	0.1596	MAE	0.2880	Time	107.078552
Sample size	32	iteration number	441	MSE	0.1346	MAE	0.2498	Time	105.911970
Sample size	32	iteration number	451	MSE	0.1667	MAE	0.3348	Time	111.217260
Sample size	32	iteration number	461	MSE	0.2288	MAE	0.2618	Time	108.930349
Sample size	32	iteration number	471	MSE	0.1270	MAE	0.2411	Time	107.630014
Sample size	32	iteration number	481	MSE	0.0726	MAE	0.2209	Time	109.687090
Sample size	32	iteration number	491	MSE	0.2139	MAE	0.3157	Time	106.511116
Sample size	32	iteration number	501	MSE	0.1325	MAE	0.2701	Time	107.081652
Sample size	32	iteration number	511	MSE	0.4703	MAE	0.4626	Time	107.785225
Sample size	32	iteration number	521	MSE	0.1792	MAE	0.2970	Time	112.086535
Sample size	32	iteration number	531	MSE	0.3006	MAE	0.3322	Time	114.791632
Sample size	32	iteration number	541	MSE	0.1036	MAE	0.2244	Time	107.793093
Sample size	32	iteration number	551	MSE	0.2383	MAE	0.3171	Time	113.776207
Sample size	32	iteration number	561	MSE	0.0936	MAE	0.2204	Time	115.132809
Sample size	32	iteration number	571	MSE	0.1578	MAE	0.3119	Time	105.851650
Sample size	32	iteration number	581	MSE	0.1309	MAE	0.2504	Time	107.020378
Sample size	32	iteration number	591	MSE	0.1283	MAE	0.2441	Time	107.668400
Sample size	32	iteration number	601	MSE	0.1160	MAE	0.2812	Time	108.039141
Sample size	32	iteration number	611	MSE	0.0887	MAE	0.2190	Time	107.561111
Sample size	32	iteration number	621	MSE	0.0927	MAE	0.2252	Time	112.647533
Sample size	32	iteration number	631	MSE	0.1101	MAE	0.2392	Time	108.156919
Sample size	32	iteration number	641	MSE	0.1916	MAE	0.3206	Time	109.099150
Sample size	32	iteration number	651	MSE	0.1531	MAE	0.2700	Time	109.302759
Sample size	32	iteration number	661	MSE	0.1049	MAE	0.2385	Time	104.348421
Sample size	32	iteration number	671	MSE	0.0299	MAE	0.1383	Time	106.510401
Sample size	32	iteration number	681	MSE	0.1883	MAE	0.2905	Time	106.752157
Sample size	32	iteration number	691	MSE	0.1436	MAE	0.2814	Time	106.723547
Sample size	32	iteration number	701	MSE	0.0733	MAE	0.1861	Time	108.959913
Sample size	32	iteration number	711	MSE	0.1747	MAE	0.2905	Time	113.890409
Sample size	32	iteration number	721	MSE	0.1615	MAE	0.2808	Time	105.839729
Sample size	32	iteration number	731	MSE	0.1269	MAE	0.2876	Time	107.475996
Sample size	32	iteration number	741	MSE	0.2117	MAE	0.3445	Time	107.527971
Sample size	32	iteration number	751	MSE	0.0941	MAE	0.2353	Time	113.234520
Sample size	32	iteration number	761	MSE	0.1845	MAE	0.2935	Time	112.207651
Sample size	32	iteration number	771	MSE	0.1603	MAE	0.3034	Time	108.115435
Sample size	32	iteration number	781	MSE	0.1129	MAE	0.2696	Time	108.979940
Sample size	32	iteration number	791	MSE	0.0841	MAE	0.2274	Time	118.249416
Sample size	32	iteration number	801	MSE	0.0925	MAE	0.2195	Time	110.401154
Sample size	32	iteration number	811	MSE	0.1218	MAE	0.2482	Time	108.787537
Sample size	32	iteration number	821	MSE	0.1946	MAE	0.2644	Time	114.778996
Sample size	32	iteration number	831	MSE	0.1683	MAE	0.2886	Time	109.090805
Sample size	32	iteration number	841	MSE	0.1127	MAE	0.2614	Time	109.374046

Sample size	32	iteration number	851	MSE	0.1481	MAE	0.3125	Time	108.285189
Sample size	32	iteration number	861	MSE	0.1077	MAE	0.2423	Time	109.073400
Sample size	32	iteration number	871	MSE	0.1397	MAE	0.2552	Time	103.258371
Sample size	32	iteration number	881	MSE	0.2482	MAE	0.3395	Time	107.571125
Sample size	32	iteration number	891	MSE	0.0746	MAE	0.1986	Time	107.233047
Sample size	32	iteration number	901	MSE	0.0967	MAE	0.2416	Time	107.018471
Sample size	32	iteration number	911	MSE	0.0741	MAE	0.2244	Time	105.915546
Sample size	32	iteration number	921	MSE	0.1374	MAE	0.2800	Time	108.154058
Sample size	32	iteration number	931	MSE	0.2307	MAE	0.3420	Time	107.156754
Sample size	32	iteration number	941	MSE	0.1204	MAE	0.2526	Time	107.789993
Sample size	32	iteration number	951	MSE	0.1094	MAE	0.2514	Time	109.695196
Sample size	32	iteration number	961	MSE	0.2251	MAE	0.2591	Time	105.753660
Sample size	32	iteration number	971	MSE	0.1058	MAE	0.2238	Time	104.228258
Sample size	32	iteration number	981	MSE	0.0774	MAE	0.2261	Time	105.931520
Sample size	32	iteration number	991	MSE	0.0825	MAE	0.2228	Time	109.480858
Sample size	32	iteration number	1001	MSE	0.0977	MAE	0.2121	Time	108.372927
Sample size	128	iteration number	1	MSE	0.0809	MAE	0.2019	Time	157.453299
Sample size	128	iteration number	11	MSE	0.1072	MAE	0.2443	Time	155.901432
Sample size	128	iteration number	21	MSE	0.1506	MAE	0.2715	Time	157.845497
Sample size	128	iteration number	31	MSE	0.0922	MAE	0.2213	Time	155.067921
Sample size	128	iteration number	41	MSE	0.1191	MAE	0.2405	Time	153.770447
Sample size	128	iteration number	51	MSE	0.1218	MAE	0.2167	Time	153.401613
Sample size	128	iteration number	61	MSE	0.1066	MAE	0.2402	Time	155.587196
Sample size	128	iteration number	71	MSE	0.1173	MAE	0.2194	Time	154.132366
Sample size	128	iteration number	81	MSE	0.1391	MAE	0.2572	Time	154.666662
Sample size	128	iteration number	91	MSE	0.0918	MAE	0.2166	Time	160.052538
Sample size	128	iteration number	101	MSE	0.0860	MAE	0.2041	Time	154.836655
Sample size	128	iteration number	111	MSE	0.1046	MAE	0.2127	Time	160.001755
Sample size	128	iteration number	121	MSE	0.0940	MAE	0.2263	Time	160.674572
Sample size	128	iteration number	131	MSE	0.1440	MAE	0.2525	Time	153.858185
Sample size	128	iteration number	141	MSE	0.1089	MAE	0.2378	Time	157.707691
Sample size	128	iteration number	151	MSE	0.1286	MAE	0.2546	Time	156.742096
Sample size	128	iteration number	161	MSE	0.1377	MAE	0.2395	Time	156.768799
Sample size	128	iteration number	171	MSE	0.1236	MAE	0.2261	Time	155.079126
Sample size	128	iteration number	181	MSE	0.1757	MAE	0.2867	Time	151.708126
Sample size	128	iteration number	191	MSE	0.1548	MAE	0.2416	Time	161.392927
Sample size	128	iteration number	201	MSE	0.0870	MAE	0.2202	Time	153.826714
Sample size	128	iteration number	211	MSE	0.0882	MAE	0.2182	Time	152.835131
Sample size	128	iteration number	221	MSE	0.1290	MAE	0.2448	Time	159.835100
Sample size	128	iteration number	231	MSE	0.0911	MAE	0.2162	Time	153.860331
Sample size	128	iteration number	241	MSE	0.0968	MAE	0.2276	Time	155.947924
Sample size	128	iteration number	251	MSE	0.1009	MAE	0.2292	Time	153.896809
Sample size	128	iteration number	261	MSE	0.0979	MAE	0.2124	Time	154.290199
Sample size	128	iteration number	271	MSE	0.0960	MAE	0.2161	Time	153.170586
Sample size	128	iteration number	281	MSE	0.0967	MAE	0.2016	Time	153.917789
Sample size	128	iteration number	291	MSE	0.1127	MAE	0.2069	Time	156.054258
Sample size	128	iteration number	301	MSE	0.0881	MAE	0.1954	Time	155.501842
Sample size	128	iteration number	311	MSE	0.1757	MAE	0.2747	Time	156.705379

Sample size	128	iteration number	321	MSE	0.0808	MAE	0.2081	Time	155.234575
Sample size	128	iteration number	331	MSE	0.1048	MAE	0.2251	Time	158.791542
Sample size	128	iteration number	341	MSE	0.1286	MAE	0.2569	Time	153.782129
Sample size	128	iteration number	351	MSE	0.1227	MAE	0.2469	Time	157.235622
Sample size	128	iteration number	361	MSE	0.1678	MAE	0.2937	Time	154.797792
Sample size	128	iteration number	371	MSE	0.0872	MAE	0.2137	Time	155.803919
Sample size	128	iteration number	381	MSE	0.1222	MAE	0.2270	Time	154.669046
Sample size	128	iteration number	391	MSE	0.1319	MAE	0.2439	Time	155.096292
Sample size	128	iteration number	401	MSE	0.1107	MAE	0.2327	Time	154.300928
Sample size	128	iteration number	411	MSE	0.1247	MAE	0.2396	Time	162.825346
Sample size	128	iteration number	421	MSE	0.1065	MAE	0.2399	Time	155.696869
Sample size	128	iteration number	431	MSE	0.1166	MAE	0.2227	Time	154.034853
Sample size	128	iteration number	441	MSE	0.1114	MAE	0.2336	Time	153.184891
Sample size	128	iteration number	451	MSE	0.0781	MAE	0.1858	Time	155.972242
Sample size	128	iteration number	461	MSE	0.1471	MAE	0.2461	Time	156.067610
Sample size	128	iteration number	471	MSE	0.1287	MAE	0.2593	Time	167.557240
Sample size	128	iteration number	481	MSE	0.1130	MAE	0.2422	Time	155.010223
Sample size	128	iteration number	491	MSE	0.1016	MAE	0.2086	Time	164.391518
Sample size	128	iteration number	501	MSE	0.1662	MAE	0.2774	Time	155.107975
Sample size	128	iteration number	511	MSE	0.1187	MAE	0.2419	Time	154.377699
Sample size	128	iteration number	521	MSE	0.1053	MAE	0.2248	Time	163.006067
Sample size	128	iteration number	531	MSE	0.1095	MAE	0.2367	Time	152.789831
Sample size	128	iteration number	541	MSE	0.1160	MAE	0.2410	Time	154.630184
Sample size	128	iteration number	551	MSE	0.1358	MAE	0.2542	Time	153.218985
Sample size	128	iteration number	561	MSE	0.1385	MAE	0.2392	Time	163.444996
Sample size	128	iteration number	571	MSE	0.1078	MAE	0.2436	Time	153.837919
Sample size	128	iteration number	581	MSE	0.1439	MAE	0.2561	Time	166.818142
Sample size	128	iteration number	591	MSE	0.1327	MAE	0.2315	Time	156.110287
Sample size	128	iteration number	601	MSE	0.1090	MAE	0.2353	Time	153.063774
Sample size	128	iteration number	611	MSE	0.0839	MAE	0.1945	Time	158.921957
Sample size	128	iteration number	621	MSE	0.1008	MAE	0.2277	Time	157.111168
Sample size	128	iteration number	631	MSE	0.1444	MAE	0.2579	Time	150.013208
Sample size	128	iteration number	641	MSE	0.1196	MAE	0.2253	Time	156.994820
Sample size	128	iteration number	651	MSE	0.0928	MAE	0.1994	Time	155.798912
Sample size	128	iteration number	661	MSE	0.0986	MAE	0.2203	Time	152.577877
Sample size	128	iteration number	671	MSE	0.0833	MAE	0.2073	Time	156.449080
Sample size	128	iteration number	681	MSE	0.0825	MAE	0.1984	Time	154.718161
Sample size	128	iteration number	691	MSE	0.0942	MAE	0.2128	Time	151.053905
Sample size	128	iteration number	701	MSE	0.0780	MAE	0.1967	Time	166.045189
Sample size	128	iteration number	711	MSE	0.1657	MAE	0.2657	Time	156.754255
Sample size	128	iteration number	721	MSE	0.1118	MAE	0.2352	Time	161.048174
Sample size	128	iteration number	731	MSE	0.0689	MAE	0.1903	Time	155.667782
Sample size	128	iteration number	741	MSE	0.0742	MAE	0.1930	Time	155.841589
Sample size	128	iteration number	751	MSE	0.1070	MAE	0.2306	Time	154.063702
Sample size	128	iteration number	761	MSE	0.1185	MAE	0.2431	Time	150.608301
Sample size	128	iteration number	771	MSE	0.0989	MAE	0.2225	Time	156.491041
Sample size	128	iteration number	781	MSE	0.1132	MAE	0.2321	Time	156.325340
Sample size	128	iteration number	791	MSE	0.1017	MAE	0.2291	Time	158.656836

Sample size	128	iteration number	801	MSE	0.1104	MAE	0.2362	Time	160.169363
Sample size	128	iteration number	811	MSE	0.1158	MAE	0.2390	Time	156.911612
Sample size	128	iteration number	821	MSE	0.1205	MAE	0.2464	Time	157.253742
Sample size	128	iteration number	831	MSE	0.1016	MAE	0.2435	Time	157.309055
Sample size	128	iteration number	841	MSE	0.0790	MAE	0.1991	Time	154.819250
Sample size	128	iteration number	851	MSE	0.1583	MAE	0.2702	Time	152.567863
Sample size	128	iteration number	861	MSE	0.1237	MAE	0.2465	Time	157.106876
Sample size	128	iteration number	871	MSE	0.1066	MAE	0.2115	Time	155.023098
Sample size	128	iteration number	881	MSE	0.0851	MAE	0.2062	Time	160.370111
Sample size	128	iteration number	891	MSE	0.1013	MAE	0.2232	Time	158.124685
Sample size	128	iteration number	901	MSE	0.0924	MAE	0.2125	Time	156.089783
Sample size	128	iteration number	911	MSE	0.1412	MAE	0.2564	Time	153.940201
Sample size	128	iteration number	921	MSE	0.1140	MAE	0.2145	Time	152.600527
Sample size	128	iteration number	931	MSE	0.0884	MAE	0.2073	Time	151.206017
Sample size	128	iteration number	941	MSE	0.1161	MAE	0.2294	Time	152.059555
Sample size	128	iteration number	951	MSE	0.0985	MAE	0.2131	Time	156.215429
Sample size	128	iteration number	961	MSE	0.1006	MAE	0.2109	Time	154.983521
Sample size	128	iteration number	971	MSE	0.1333	MAE	0.2602	Time	156.404495
Sample size	128	iteration number	981	MSE	0.1094	MAE	0.2246	Time	157.832861
Sample size	128	iteration number	991	MSE	0.0948	MAE	0.2075	Time	163.284540
Sample size	128	iteration number	1001	MSE	0.0603	MAE	0.1764	Time	155.289412
Sample size	512	iteration number	1	MSE	0.1189	MAE	0.2339	Time	354.246616
Sample size	512	iteration number	11	MSE	0.1150	MAE	0.2153	Time	345.412016
Sample size	512	iteration number	21	MSE	0.1108	MAE	0.2199	Time	343.708038
Sample size	512	iteration number	31	MSE	0.1228	MAE	0.2353	Time	350.221634
Sample size	512	iteration number	41	MSE	0.0886	MAE	0.2053	Time	348.923445
Sample size	512	iteration number	51	MSE	0.1170	MAE	0.2380	Time	354.820013
Sample size	512	iteration number	61	MSE	0.1275	MAE	0.2327	Time	350.621223
Sample size	512	iteration number	71	MSE	0.0929	MAE	0.2035	Time	348.690987
Sample size	512	iteration number	81	MSE	0.1175	MAE	0.2262	Time	352.145433
Sample size	512	iteration number	91	MSE	0.1124	MAE	0.2348	Time	348.118305
Sample size	512	iteration number	101	MSE	0.1078	MAE	0.2197	Time	346.410036
Sample size	512	iteration number	111	MSE	0.1079	MAE	0.2206	Time	349.861383
Sample size	512	iteration number	121	MSE	0.0857	MAE	0.2025	Time	349.280834
Sample size	512	iteration number	131	MSE	0.1107	MAE	0.2224	Time	340.249777
Sample size	512	iteration number	141	MSE	0.1053	MAE	0.2150	Time	342.718363
Sample size	512	iteration number	151	MSE	0.0957	MAE	0.2124	Time	347.786188
Sample size	512	iteration number	161	MSE	0.1010	MAE	0.2109	Time	348.652363
Sample size	512	iteration number	171	MSE	0.0903	MAE	0.2015	Time	349.757671
Sample size	512	iteration number	181	MSE	0.1038	MAE	0.2213	Time	354.754686
Sample size	512	iteration number	191	MSE	0.1015	MAE	0.2172	Time	347.750425
Sample size	512	iteration number	201	MSE	0.1220	MAE	0.2336	Time	357.282400
Sample size	512	iteration number	211	MSE	0.1286	MAE	0.2401	Time	362.968445
Sample size	512	iteration number	221	MSE	0.1176	MAE	0.2330	Time	349.036217
Sample size	512	iteration number	231	MSE	0.1137	MAE	0.2154	Time	346.295834
Sample size	512	iteration number	241	MSE	0.1054	MAE	0.2250	Time	354.051590
Sample size	512	iteration number	251	MSE	0.1213	MAE	0.2358	Time	353.163004
Sample size	512	iteration number	261	MSE	0.1097	MAE	0.2210	Time	361.499548

Sample size	512	iteration number	271	MSE	0.1101	MAE	0.2123	Time	351.383209
Sample size	512	iteration number	281	MSE	0.1042	MAE	0.2093	Time	354.269266
Sample size	512	iteration number	291	MSE	0.1135	MAE	0.2295	Time	354.049683
Sample size	512	iteration number	301	MSE	0.0929	MAE	0.2018	Time	357.745886
Sample size	512	iteration number	311	MSE	0.1278	MAE	0.2324	Time	360.123873
Sample size	512	iteration number	321	MSE	0.1077	MAE	0.2208	Time	351.947546
Sample size	512	iteration number	331	MSE	0.0913	MAE	0.2070	Time	356.229544
Sample size	512	iteration number	341	MSE	0.1063	MAE	0.2179	Time	341.962814
Sample size	512	iteration number	351	MSE	0.1110	MAE	0.2208	Time	351.145267
Sample size	512	iteration number	361	MSE	0.1166	MAE	0.2279	Time	348.304033
Sample size	512	iteration number	371	MSE	0.1037	MAE	0.2109	Time	349.361181
Sample size	512	iteration number	381	MSE	0.1148	MAE	0.2225	Time	345.129490
Sample size	512	iteration number	391	MSE	0.0980	MAE	0.2093	Time	357.655048
Sample size	512	iteration number	401	MSE	0.1016	MAE	0.2212	Time	350.904703
Sample size	512	iteration number	411	MSE	0.0988	MAE	0.2161	Time	357.674599
Sample size	512	iteration number	421	MSE	0.0874	MAE	0.2016	Time	344.200134
Sample size	512	iteration number	431	MSE	0.0989	MAE	0.2054	Time	354.144573
Sample size	512	iteration number	441	MSE	0.1075	MAE	0.2273	Time	352.936029
Sample size	512	iteration number	451	MSE	0.1013	MAE	0.2151	Time	352.892160
Sample size	512	iteration number	461	MSE	0.1075	MAE	0.2144	Time	353.129625
Sample size	512	iteration number	471	MSE	0.1024	MAE	0.2096	Time	355.608225
Sample size	512	iteration number	481	MSE	0.1057	MAE	0.2130	Time	347.187996
Sample size	512	iteration number	491	MSE	0.1062	MAE	0.2183	Time	347.598314
Sample size	512	iteration number	501	MSE	0.1204	MAE	0.2265	Time	346.058607
Sample size	512	iteration number	511	MSE	0.1075	MAE	0.2208	Time	350.479364
Sample size	512	iteration number	521	MSE	0.0896	MAE	0.2013	Time	345.561504
Sample size	512	iteration number	531	MSE	0.0853	MAE	0.2021	Time	348.217964
Sample size	512	iteration number	541	MSE	0.1066	MAE	0.2201	Time	346.149921
Sample size	512	iteration number	551	MSE	0.1042	MAE	0.2129	Time	349.385500
Sample size	512	iteration number	561	MSE	0.1185	MAE	0.2310	Time	351.782560
Sample size	512	iteration number	571	MSE	0.0941	MAE	0.2178	Time	350.383043
Sample size	512	iteration number	581	MSE	0.1075	MAE	0.2222	Time	348.910332
Sample size	512	iteration number	591	MSE	0.1123	MAE	0.2208	Time	351.239920
Sample size	512	iteration number	601	MSE	0.1117	MAE	0.2168	Time	348.907948
Sample size	512	iteration number	611	MSE	0.1070	MAE	0.2205	Time	350.578785
Sample size	512	iteration number	621	MSE	0.1079	MAE	0.2254	Time	345.898867
Sample size	512	iteration number	631	MSE	0.0924	MAE	0.2123	Time	344.327927
Sample size	512	iteration number	641	MSE	0.0989	MAE	0.2057	Time	346.133232
Sample size	512	iteration number	651	MSE	0.0932	MAE	0.1992	Time	351.406097
Sample size	512	iteration number	661	MSE	0.1114	MAE	0.2168	Time	355.288744
Sample size	512	iteration number	671	MSE	0.1229	MAE	0.2306	Time	357.109070
Sample size	512	iteration number	681	MSE	0.1059	MAE	0.2155	Time	360.365391
Sample size	512	iteration number	691	MSE	0.0899	MAE	0.2044	Time	352.690220
Sample size	512	iteration number	701	MSE	0.1095	MAE	0.2205	Time	355.473757
Sample size	512	iteration number	711	MSE	0.0915	MAE	0.2084	Time	356.573582
Sample size	512	iteration number	721	MSE	0.1016	MAE	0.2187	Time	352.117062
Sample size	512	iteration number	731	MSE	0.1123	MAE	0.2252	Time	348.996401
Sample size	512	iteration number	741	MSE	0.0944	MAE	0.2102	Time	359.152317

Sample size	512	iteration number	751	MSE	0.1099	MAE	0.2161	Time	353.363991
Sample size	512	iteration number	761	MSE	0.1127	MAE	0.2169	Time	345.863581
Sample size	512	iteration number	771	MSE	0.0950	MAE	0.2183	Time	353.575468
Sample size	512	iteration number	781	MSE	0.1151	MAE	0.2291	Time	349.410295
Sample size	512	iteration number	791	MSE	0.1110	MAE	0.2211	Time	350.284100
Sample size	512	iteration number	801	MSE	0.1035	MAE	0.2154	Time	359.100103
Sample size	512	iteration number	811	MSE	0.1160	MAE	0.2238	Time	361.731052
Sample size	512	iteration number	821	MSE	0.1082	MAE	0.2211	Time	346.385479
Sample size	512	iteration number	831	MSE	0.1081	MAE	0.2154	Time	349.467039
Sample size	512	iteration number	841	MSE	0.1047	MAE	0.2218	Time	346.148729
Sample size	512	iteration number	851	MSE	0.1150	MAE	0.2251	Time	348.840237
Sample size	512	iteration number	861	MSE	0.1030	MAE	0.2183	Time	367.925167
Sample size	512	iteration number	871	MSE	0.1009	MAE	0.2253	Time	371.340275
Sample size	512	iteration number	881	MSE	0.1121	MAE	0.2241	Time	344.470739
Sample size	512	iteration number	891	MSE	0.1227	MAE	0.2320	Time	347.895861
Sample size	512	iteration number	901	MSE	0.1139	MAE	0.2223	Time	364.109278
Sample size	512	iteration number	911	MSE	0.1072	MAE	0.2175	Time	345.032930
Sample size	512	iteration number	921	MSE	0.1154	MAE	0.2302	Time	347.341776
Sample size	512	iteration number	931	MSE	0.1064	MAE	0.2098	Time	352.187872
Sample size	512	iteration number	941	MSE	0.1110	MAE	0.2242	Time	351.804495
Sample size	512	iteration number	951	MSE	0.1012	MAE	0.2192	Time	347.592354
Sample size	512	iteration number	961	MSE	0.1140	MAE	0.2217	Time	347.561836
Sample size	512	iteration number	971	MSE	0.0888	MAE	0.2044	Time	360.013723
Sample size	512	iteration number	981	MSE	0.1071	MAE	0.2219	Time	356.436729
Sample size	512	iteration number	991	MSE	0.1099	MAE	0.2266	Time	347.207069
Sample size	512	iteration number	1001	MSE	0.0918	MAE	0.2097	Time	354.120731
Sample size	2048	iteration number	1	MSE	0.1150	MAE	0.2207	Time	1097.87917
Sample size	2048	iteration number	11	MSE	0.1062	MAE	0.2165	Time	1097.51915
Sample size	2048	iteration number	21	MSE	0.1092	MAE	0.2183	Time	1093.75000
Sample size	2048	iteration number	31	MSE	0.0965	MAE	0.2026	Time	1183.15792
Sample size	2048	iteration number	41	MSE	0.1064	MAE	0.2168	Time	1114.50696
Sample size	2048	iteration number	51	MSE	0.1010	MAE	0.2104	Time	1088.00125
Sample size	2048	iteration number	61	MSE	0.1052	MAE	0.2133	Time	1084.51628
Sample size	2048	iteration number	71	MSE	0.1067	MAE	0.2160	Time	1098.33598
Sample size	2048	iteration number	81	MSE	0.1067	MAE	0.2148	Time	1112.25175
Sample size	2048	iteration number	91	MSE	0.1105	MAE	0.2245	Time	1103.31344
Sample size	2048	iteration number	101	MSE	0.1094	MAE	0.2199	Time	1096.81367
Sample size	2048	iteration number	111	MSE	0.0984	MAE	0.2105	Time	1096.20213
Sample size	2048	iteration number	121	MSE	0.0905	MAE	0.1998	Time	1099.94936
Sample size	2048	iteration number	131	MSE	0.1022	MAE	0.2155	Time	1090.76595
Sample size	2048	iteration number	141	MSE	0.1013	MAE	0.2101	Time	1105.27634
Sample size	2048	iteration number	151	MSE	0.1067	MAE	0.2143	Time	1100.10027
Sample size	2048	iteration number	161	MSE	0.1006	MAE	0.2140	Time	1099.11704
Sample size	2048	iteration number	171	MSE	0.1006	MAE	0.2155	Time	1096.87495
Sample size	2048	iteration number	181	MSE	0.0994	MAE	0.2075	Time	1105.14545
Sample size	2048	iteration number	191	MSE	0.0947	MAE	0.2034	Time	1092.38410
Sample size	2048	iteration number	201	MSE	0.1118	MAE	0.2212	Time	1101.84001
Sample size	2048	iteration number	211	MSE	0.1072	MAE	0.2182	Time	1092.05579

Sample size	2048	iteration number	221	MSE	0.1058	MAE	0.2154	Time	1100.03924
Sample size	2048	iteration number	231	MSE	0.1104	MAE	0.2170	Time	1091.43161
Sample size	2048	iteration number	241	MSE	0.1033	MAE	0.2184	Time	1093.28270
Sample size	2048	iteration number	251	MSE	0.1025	MAE	0.2138	Time	1094.25377
Sample size	2048	iteration number	261	MSE	0.1061	MAE	0.2176	Time	1101.51410
Sample size	2048	iteration number	271	MSE	0.0935	MAE	0.2077	Time	1093.90425
Sample size	2048	iteration number	281	MSE	0.1017	MAE	0.2157	Time	1113.89184
Sample size	2048	iteration number	291	MSE	0.1065	MAE	0.2174	Time	1097.11194
Sample size	2048	iteration number	301	MSE	0.1009	MAE	0.2125	Time	1096.32921
Sample size	2048	iteration number	311	MSE	0.1002	MAE	0.2128	Time	1093.70064
Sample size	2048	iteration number	321	MSE	0.0942	MAE	0.2073	Time	1100.28815
Sample size	2048	iteration number	331	MSE	0.1137	MAE	0.2233	Time	1093.96243
Sample size	2048	iteration number	341	MSE	0.1100	MAE	0.2241	Time	1100.54087
Sample size	2048	iteration number	351	MSE	0.0999	MAE	0.2131	Time	1097.48363
Sample size	2048	iteration number	361	MSE	0.1074	MAE	0.2160	Time	1092.15951
Sample size	2048	iteration number	371	MSE	0.0998	MAE	0.2102	Time	1099.03240
Sample size	2048	iteration number	381	MSE	0.1015	MAE	0.2119	Time	1093.56522
Sample size	2048	iteration number	391	MSE	0.1096	MAE	0.2177	Time	1094.91396
Sample size	2048	iteration number	401	MSE	0.1095	MAE	0.2215	Time	1100.89874
Sample size	2048	iteration number	411	MSE	0.1023	MAE	0.2157	Time	1100.05164
Sample size	2048	iteration number	421	MSE	0.0969	MAE	0.2079	Time	1102.19168
Sample size	2048	iteration number	431	MSE	0.0985	MAE	0.2103	Time	1095.77965
Sample size	2048	iteration number	441	MSE	0.1080	MAE	0.2228	Time	1097.46980
Sample size	2048	iteration number	451	MSE	0.0976	MAE	0.2100	Time	1098.36888
Sample size	2048	iteration number	461	MSE	0.0993	MAE	0.2140	Time	1103.45602
Sample size	2048	iteration number	471	MSE	0.1040	MAE	0.2170	Time	1101.65691
Sample size	2048	iteration number	481	MSE	0.1088	MAE	0.2195	Time	1097.24783
Sample size	2048	iteration number	491	MSE	0.0967	MAE	0.2060	Time	1131.98638
Sample size	2048	iteration number	501	MSE	0.1109	MAE	0.2195	Time	1116.42432
Sample size	2048	iteration number	511	MSE	0.1072	MAE	0.2152	Time	1115.19956
Sample size	2048	iteration number	521	MSE	0.1082	MAE	0.2209	Time	1095.90411
Sample size	2048	iteration number	531	MSE	0.1154	MAE	0.2247	Time	1080.25527
Sample size	2048	iteration number	541	MSE	0.1144	MAE	0.2280	Time	1084.78879
Sample size	2048	iteration number	551	MSE	0.0972	MAE	0.2087	Time	1161.30685
Sample size	2048	iteration number	561	MSE	0.1041	MAE	0.2196	Time	1086.83514
Sample size	2048	iteration number	571	MSE	0.1110	MAE	0.2192	Time	1079.40197
Sample size	2048	iteration number	581	MSE	0.1053	MAE	0.2155	Time	1085.24537
Sample size	2048	iteration number	591	MSE	0.1030	MAE	0.2164	Time	1083.12702
Sample size	2048	iteration number	601	MSE	0.1174	MAE	0.2258	Time	1186.82241
Sample size	2048	iteration number	611	MSE	0.1020	MAE	0.2132	Time	1100.48532
Sample size	2048	iteration number	621	MSE	0.1095	MAE	0.2165	Time	1091.06302
Sample size	2048	iteration number	631	MSE	0.1066	MAE	0.2149	Time	1084.49745
Sample size	2048	iteration number	641	MSE	0.1045	MAE	0.2114	Time	1090.63243
Sample size	2048	iteration number	651	MSE	0.1010	MAE	0.2156	Time	1087.37754
Sample size	2048	iteration number	661	MSE	0.1013	MAE	0.2103	Time	1090.26813
Sample size	2048	iteration number	671	MSE	0.0973	MAE	0.2103	Time	1164.64424
Sample size	2048	iteration number	681	MSE	0.1052	MAE	0.2159	Time	1097.15294
Sample size	2048	iteration number	691	MSE	0.0954	MAE	0.2072	Time	1105.07154

Sample size	2048	iteration number	701	MSE	0.1070	MAE	0.2132	Time	1094.28572
Sample size	2048	iteration number	711	MSE	0.1078	MAE	0.2196	Time	1100.12483
Sample size	2048	iteration number	721	MSE	0.1073	MAE	0.2114	Time	1092.65232
Sample size	2048	iteration number	731	MSE	0.1122	MAE	0.2213	Time	1096.46892
Sample size	2048	iteration number	741	MSE	0.1007	MAE	0.2106	Time	1097.63455
Sample size	2048	iteration number	751	MSE	0.0978	MAE	0.2116	Time	1097.43213
Sample size	2048	iteration number	761	MSE	0.1055	MAE	0.2172	Time	1099.09486
Sample size	2048	iteration number	771	MSE	0.1126	MAE	0.2226	Time	1098.81377
Sample size	2048	iteration number	781	MSE	0.0959	MAE	0.2072	Time	1094.04873
Sample size	2048	iteration number	791	MSE	0.1035	MAE	0.2114	Time	1100.92711
Sample size	2048	iteration number	801	MSE	0.1079	MAE	0.2154	Time	1121.84619
Sample size	2048	iteration number	811	MSE	0.1126	MAE	0.2217	Time	1131.13141
Sample size	2048	iteration number	821	MSE	0.1101	MAE	0.2178	Time	1100.23808
Sample size	2048	iteration number	831	MSE	0.1013	MAE	0.2115	Time	1098.53744
Sample size	2048	iteration number	841	MSE	0.1071	MAE	0.2177	Time	1100.36969
Sample size	2048	iteration number	851	MSE	0.1104	MAE	0.2193	Time	1097.55253
Sample size	2048	iteration number	861	MSE	0.1005	MAE	0.2079	Time	1098.45399
Sample size	2048	iteration number	871	MSE	0.0992	MAE	0.2051	Time	1093.54972
Sample size	2048	iteration number	881	MSE	0.1019	MAE	0.2124	Time	1097.35560
Sample size	2048	iteration number	891	MSE	0.0984	MAE	0.2063	Time	1096.86803
Sample size	2048	iteration number	901	MSE	0.1078	MAE	0.2156	Time	1126.56307
Sample size	2048	iteration number	911	MSE	0.1108	MAE	0.2208	Time	1102.98633
Sample size	2048	iteration number	921	MSE	0.1001	MAE	0.2103	Time	1105.39364
Sample size	2048	iteration number	931	MSE	0.1104	MAE	0.2129	Time	1099.63131
Sample size	2048	iteration number	941	MSE	0.1157	MAE	0.2258	Time	1103.41596
Sample size	2048	iteration number	951	MSE	0.1207	MAE	0.2275	Time	1123.12865
Sample size	2048	iteration number	961	MSE	0.1027	MAE	0.2128	Time	1097.27144
Sample size	2048	iteration number	971	MSE	0.1047	MAE	0.2123	Time	1109.10725
Sample size	2048	iteration number	981	MSE	0.1225	MAE	0.2243	Time	1107.51223
Sample size	2048	iteration number	991	MSE	0.1093	MAE	0.2230	Time	1112.69640
Sample size	2048	iteration number	1001	MSE	0.1002	MAE	0.2139	Time	1096.48251
Sample size	2048	iteration number	1011	MSE	0.1118	MAE	0.2214	Time	1098.91271
Sample size	2048	iteration number	1021	MSE	0.1028	MAE	0.2141	Time	1091.45927
Sample size	2048	iteration number	1031	MSE	0.1067	MAE	0.2153	Time	1090.89541
Sample size	2048	iteration number	1041	MSE	0.1115	MAE	0.2156	Time	1126.56688
Sample size	2048	iteration number	1051	MSE	0.1036	MAE	0.2136	Time	1113.55519
Sample size	2048	iteration number	1061	MSE	0.1012	MAE	0.2044	Time	1108.20937
Sample size	2048	iteration number	1071	MSE	0.0984	MAE	0.2073	Time	1099.05123
Sample size	2048	iteration number	1081	MSE	0.0985	MAE	0.2096	Time	1097.87488
Sample size	2048	iteration number	1091	MSE	0.1101	MAE	0.2190	Time	1098.63591
Sample size	2048	iteration number	1101	MSE	0.1070	MAE	0.2146	Time	1101.92585
Sample size	2048	iteration number	1111	MSE	0.1080	MAE	0.2155	Time	1103.01041
Sample size	2048	iteration number	1121	MSE	0.0971	MAE	0.2132	Time	1107.69176
Sample size	2048	iteration number	1131	MSE	0.1013	MAE	0.2087	Time	1102.98419
Sample size	2048	iteration number	1141	MSE	0.0954	MAE	0.2080	Time	1100.64697
Sample size	2048	iteration number	1151	MSE	0.0972	MAE	0.2076	Time	1099.80154
Sample size	2048	iteration number	1161	MSE	0.1080	MAE	0.2150	Time	1101.67145
Sample size	2048	iteration number	1171	MSE	0.1051	MAE	0.2169	Time	1096.98605

Sample size	2048	iteration number	1181	MSE	0.0990	MAE	0.2146	Time	1089.36071
Sample size	2048	iteration number	1191	MSE	0.1016	MAE	0.2119	Time	1091.93205
Sample size	2048	iteration number	1201	MSE	0.1141	MAE	0.2237	Time	1099.65705
Sample size	2048	iteration number	1211	MSE	0.0971	MAE	0.2047	Time	1098.01936
Sample size	2048	iteration number	1221	MSE	0.1062	MAE	0.2167	Time	1095.72386
Sample size	2048	iteration number	1231	MSE	0.1021	MAE	0.2112	Time	1100.62027
Sample size	2048	iteration number	1241	MSE	0.1037	MAE	0.2137	Time	1104.99668
Sample size	2048	iteration number	1251	MSE	0.1061	MAE	0.2168	Time	1096.16398
Sample size	2048	iteration number	1261	MSE	0.1102	MAE	0.2174	Time	1095.68738
Sample size	2048	iteration number	1271	MSE	0.1030	MAE	0.2139	Time	1092.80705
Sample size	2048	iteration number	1281	MSE	0.1070	MAE	0.2198	Time	1185.26172
Sample size	2048	iteration number	1291	MSE	0.1156	MAE	0.2192	Time	1102.58102
Sample size	2048	iteration number	1301	MSE	0.1097	MAE	0.2254	Time	1101.98664
Sample size	2048	iteration number	1311	MSE	0.0921	MAE	0.1975	Time	1098.79207
Sample size	2048	iteration number	1321	MSE	0.1045	MAE	0.2157	Time	1098.85478
Sample size	2048	iteration number	1331	MSE	0.1035	MAE	0.2153	Time	1094.24877
Sample size	2048	iteration number	1341	MSE	0.1036	MAE	0.2154	Time	1103.91712
Sample size	2048	iteration number	1351	MSE	0.1081	MAE	0.2159	Time	1105.72099
Sample size	2048	iteration number	1361	MSE	0.1031	MAE	0.2101	Time	1096.65966
Sample size	2048	iteration number	1371	MSE	0.1047	MAE	0.2126	Time	1099.33114
Sample size	2048	iteration number	1381	MSE	0.1095	MAE	0.2185	Time	1104.92062
Sample size	2048	iteration number	1391	MSE	0.1035	MAE	0.2115	Time	1103.19352
Sample size	2048	iteration number	1401	MSE	0.1021	MAE	0.2140	Time	1097.98836
Sample size	2048	iteration number	1411	MSE	0.1021	MAE	0.2087	Time	1099.60818
Sample size	2048	iteration number	1421	MSE	0.1084	MAE	0.2187	Time	1100.57401
Sample size	2048	iteration number	1431	MSE	0.1028	MAE	0.2118	Time	1107.88703
Sample size	2048	iteration number	1441	MSE	0.1183	MAE	0.2276	Time	1097.81885
Sample size	2048	iteration number	1451	MSE	0.1167	MAE	0.2214	Time	1092.97561
Sample size	2048	iteration number	1461	MSE	0.1000	MAE	0.2132	Time	1087.07451
Sample size	2048	iteration number	1471	MSE	0.0984	MAE	0.2033	Time	1087.09168
Sample size	2048	iteration number	1481	MSE	0.1054	MAE	0.2151	Time	1089.06626
Sample size	2048	iteration number	1491	MSE	0.1091	MAE	0.2231	Time	1097.97787
Sample size	2048	iteration number	1501	MSE	0.1087	MAE	0.2163	Time	1109.46273
Sample size	2048	iteration number	1511	MSE	0.1031	MAE	0.2139	Time	1085.12425
Sample size	2048	iteration number	1521	MSE	0.1202	MAE	0.2219	Time	1088.58561
Sample size	2048	iteration number	1531	MSE	0.1071	MAE	0.2114	Time	1099.15828
Sample size	2048	iteration number	1541	MSE	0.1010	MAE	0.2106	Time	1085.38723
Sample size	2048	iteration number	1551	MSE	0.1022	MAE	0.2112	Time	1087.52965
Sample size	2048	iteration number	1561	MSE	0.1099	MAE	0.2122	Time	1086.60244
Sample size	2048	iteration number	1571	MSE	0.1115	MAE	0.2206	Time	1083.68754
Sample size	2048	iteration number	1581	MSE	0.1065	MAE	0.2205	Time	1083.16803
Sample size	2048	iteration number	1591	MSE	0.1024	MAE	0.2106	Time	1084.13910
Sample size	2048	iteration number	1601	MSE	0.1084	MAE	0.2176	Time	1082.43274
Sample size	2048	iteration number	1611	MSE	0.1139	MAE	0.2220	Time	1087.35585
Sample size	2048	iteration number	1621	MSE	0.0996	MAE	0.2153	Time	1083.34660
Sample size	2048	iteration number	1631	MSE	0.1041	MAE	0.2144	Time	1081.12120
Sample size	2048	iteration number	1641	MSE	0.1116	MAE	0.2132	Time	1083.45580
Sample size	2048	iteration number	1651	MSE	0.0942	MAE	0.2028	Time	1087.57948

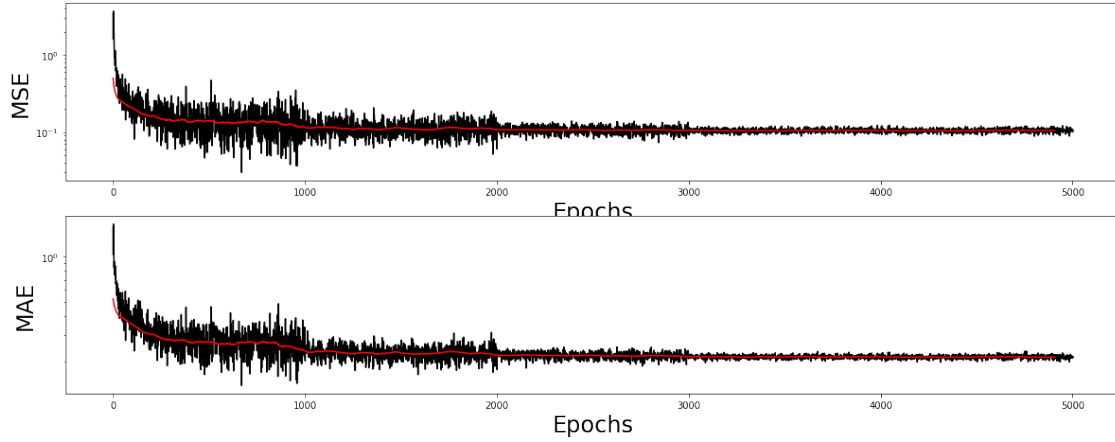
Sample size	2048	iteration number	1661	MSE	0.0965	MAE	0.2087	Time	1084.06949
Sample size	2048	iteration number	1671	MSE	0.1182	MAE	0.2265	Time	1096.07029
Sample size	2048	iteration number	1681	MSE	0.1047	MAE	0.2118	Time	1080.11555
Sample size	2048	iteration number	1691	MSE	0.1112	MAE	0.2187	Time	1084.47146
Sample size	2048	iteration number	1701	MSE	0.1085	MAE	0.2175	Time	1080.40070
Sample size	2048	iteration number	1711	MSE	0.1029	MAE	0.2116	Time	1089.06793
Sample size	2048	iteration number	1721	MSE	0.1048	MAE	0.2143	Time	1086.58671
Sample size	2048	iteration number	1731	MSE	0.1043	MAE	0.2177	Time	1085.12020
Sample size	2048	iteration number	1741	MSE	0.0996	MAE	0.2139	Time	1088.24205
Sample size	2048	iteration number	1751	MSE	0.1202	MAE	0.2346	Time	1083.65964
Sample size	2048	iteration number	1761	MSE	0.1038	MAE	0.2126	Time	1083.10604
Sample size	2048	iteration number	1771	MSE	0.1029	MAE	0.2137	Time	1084.07163
Sample size	2048	iteration number	1781	MSE	0.1051	MAE	0.2119	Time	1089.08486
Sample size	2048	iteration number	1791	MSE	0.1068	MAE	0.2185	Time	1088.00792
Sample size	2048	iteration number	1801	MSE	0.1065	MAE	0.2140	Time	1083.10675
Sample size	2048	iteration number	1811	MSE	0.1011	MAE	0.2090	Time	1086.73596
Sample size	2048	iteration number	1821	MSE	0.1098	MAE	0.2212	Time	1086.21597
Sample size	2048	iteration number	1831	MSE	0.1034	MAE	0.2134	Time	1084.23018
Sample size	2048	iteration number	1841	MSE	0.1055	MAE	0.2186	Time	1083.29868
Sample size	2048	iteration number	1851	MSE	0.1003	MAE	0.2076	Time	1088.36484
Sample size	2048	iteration number	1861	MSE	0.1006	MAE	0.2111	Time	1084.34581
Sample size	2048	iteration number	1871	MSE	0.0979	MAE	0.2096	Time	1089.08653
Sample size	2048	iteration number	1881	MSE	0.1018	MAE	0.2123	Time	1086.16995
Sample size	2048	iteration number	1891	MSE	0.1030	MAE	0.2143	Time	1084.01083
Sample size	2048	iteration number	1901	MSE	0.1185	MAE	0.2223	Time	1085.83569
Sample size	2048	iteration number	1911	MSE	0.1076	MAE	0.2150	Time	1093.05834
Sample size	2048	iteration number	1921	MSE	0.0982	MAE	0.2117	Time	1084.59115
Sample size	2048	iteration number	1931	MSE	0.1097	MAE	0.2175	Time	1085.83283
Sample size	2048	iteration number	1941	MSE	0.1030	MAE	0.2135	Time	1078.61328
Sample size	2048	iteration number	1951	MSE	0.1023	MAE	0.2072	Time	1101.62401
Sample size	2048	iteration number	1961	MSE	0.0936	MAE	0.2043	Time	1097.88537
Sample size	2048	iteration number	1971	MSE	0.1070	MAE	0.2166	Time	1098.14763
Sample size	2048	iteration number	1981	MSE	0.1019	MAE	0.2133	Time	1103.27553
Sample size	2048	iteration number	1991	MSE	0.1030	MAE	0.2122	Time	1098.01745
Sample size	2048	iteration number	2001	MSE	0.1049	MAE	0.2148	Time	1095.18837

1.6 6. PLOT LEARNING PERFORMANCE

The learning performance is plotted. The MSE, MAE, sample size, iteration number and iteration time are plotted against the number of timesteps.

Comment: 1. The parameter `number_of_timesteps_for_average` determines the length of the average. It must be a positive integer number.

```
In [8]: ### Plot learning performance
        number_of_timesteps_for_average = 100
        DeepCalib.plot_learning_performance(training_history, number_of_timesteps_for_average)
```



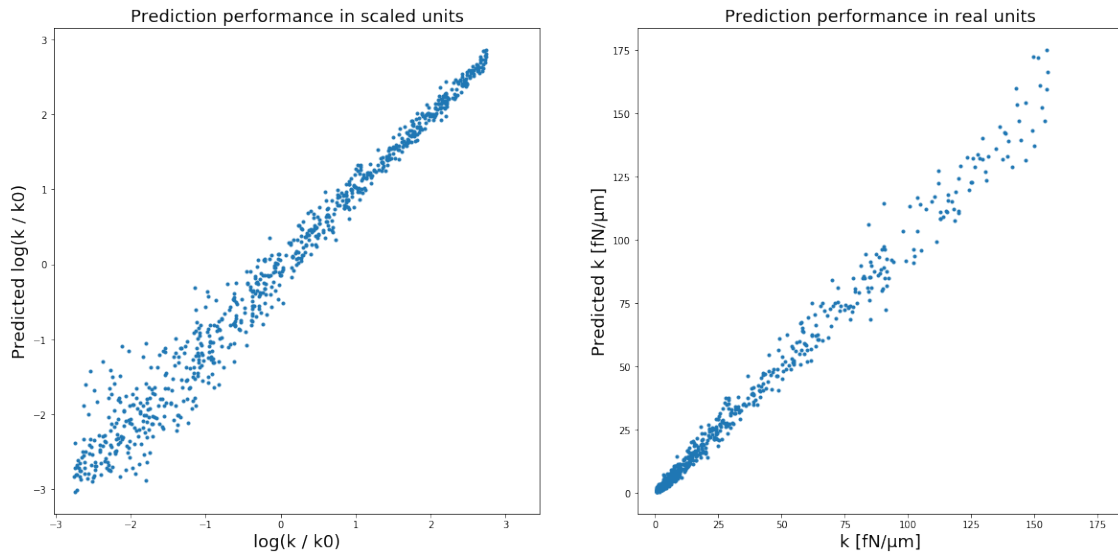
1.7 7. TEST DEEP LEARNING NETWORK ON NEW SIMULATED TRAJECTORIES

The deep learning network is tested on new simulated trajectories (parameters are defined in Section ??). The predicted values of the targets are plotted as function of their ground-truth values both in scaled and physical units.

Comments: 1. The parameter `number_of_predictions_to_show` determines the number of predictions that are shown.

```
In [9]: ### Test the predictions of the deep learning network on some generated trajectories
        number_of_predictions_to_show = 1000

        %matplotlib inline
        DeepCalib.plot_test_performance(simulate_trajectory, network, rescale_targets, number_of
```



1.8 9. SAVE DEEP LEARNING NETWORK

Comments: 1. The parameter `save_file_name` is the name of the file where the deep learning network is saved. 2. By default, the network is saved in the same folder where DeepCalib is running.

```
In [8]: save_file_name = 'Network_Example_1a.h5'  
        network.save(save_file_name)
```